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Environmental Assessment of a Waste-to-Energy Process: GSA/Pentagon Co-Fired Boiler Tests

Midwest Research Inst.
Kansas City, MO

Prepared for

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16. ABSTRACT

Midwest Research Institute (MRI), in conjunction with the General Services Administration (GSA) and the National Center for Resource Recovery (NCRR), conducted a series of emission tests at the Virginia Heating and Refrigeration Plant (VHRP) in Arlington, Virginia (this plant provides steam heat or refrigerated air to the Pentagon building). The study was designed to obtain emission data while one of the steam boilers was co-fired with different blends of coal and densified refuse-derived fuel (d-RDF).

The No. 4 boiler at VHRP was utilized for this test program. It is an underfeed retort stoker boiler rated at 70,000 lb/hr and normally uses coal as the sole fuel. For this d-RDF burn program, sampling was conducted during three fuel firing modes: coal only, 20% d-RDF + 80% coal, and 60% d-RDF + 40% coal.

Samples of the coal, d-RDF, and coal/d-RDF fuel mixtures were collected hourly and analyzed by NCRR for moisture, ash, heating value, and chemical composition. Several daily samples of bottom ash were also collected by NCRR. These were analyzed for loss-on-ignition and chemical composition.

MRI was responsible for sampling and analysis of the stack effluent. Tests were conducted for particulate concentration, gaseous criteria pollutants (SO_2, NO_x, CO, and total hydrocarbons), and chlorides. Particulate samples were also analyzed for lead content.

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ENVIRONMENTAL ASSESSMENT OF A WASTE-TO-ENERGY PROCESS

GSA/PENTAGON CO-FIRED BOILER TESTS

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report documents the results of a limited environmental assessment of a steam boiler operated by the General Services Administration in Arlington, Virginia which was test fired with two different blends of coal and densified refuse-derived fuel. The information contained herein will be of interest to those considering refuse-derived fuel as a supplemental energy source. Inquiries and comments regarding this report should be directed to the Industrial Environmental Research Laboratory.

David G. Stephan
Director
Industrial Environmental
Research Laboratory-
Cincinnati

ABSTRACT

The U.S. Environmental Protection Agency's Fuels Technology Branch in Cincinnati is currently supporting a research program to conduct environmental assessments of various types of waste-to-energy conversion systems. Under the auspices of this program, Midwest Research Institute (MRI), in conjunction with the General Services Administration (GSA) and the National Center for Resource Recovery (NCRR), conducted a series of emission tests at the Virginia Heating and Refrigeration Plant (VHRP) in Arlington, Virginia (this plant provides steam heat or refrigerated air to the Pentagon building). The study was designed to obtain emission data while one of the steam boilers was co-fired with different blends of coal and densified refuse-derived fuel (d-RDF).

The No. 4 boiler at VHRP was utilized for this test program. The steam output of this underfeed-retort stoker boiler is rated at 70,000 lb/hr, although usual maximum load is about 50,000 lb/hr. Coal is normally the sole fuel. For this d-RDF burn program, sampling was conducted during three fuel firing modes: coal only, 20% d-RDF + 80% coal, and 60% d-RDF + 40% coal. The tests were intended to be run at a single boiler load for comparative purposes, but steam output could not be held constant during much of the sampling period.

Samples of the coal, d-RDF and coal/d-RDF fuel mixtures were collected hourly and analyzed by NCRR for moisture, ash, heating value and chemical composition. Several daily samples of bottom ash were also collected by NCRR. These were analyzed for loss-on-ignition and chemical composition.

MRI was responsible for sampling and analysis of the stack effluent. Tests were conducted for particulate concentration, gaseous criteria pollutants (SO_2, NO_x, CO and total hydrocarbons) and chlorides. Particulate samples were also analyzed for lead content.

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METRIC CONVERSION FACTORS USED IN THIS REPORT

To convert from English	To Metric	Multiply by
Btu	kJ	1.055
Btu/lb	kJ/kg	2.326
ft	m	3.048 E-01
ft^2	m^2	9.290 E-02
ft^3/min	m^3/min	2.832 E-02
gal/min	liter/min	3.785
gr/scf	g/dscm	2.288
lb	kg	4.536 E-01
lb/ft^3	kg/m^3	1.603 E-01
$lb/10^6$ Btu	kg/MJ	4.300 E-01
psi	kPa	6.895
ton	Mg	9.072 E-01

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The MRI project leader is Dr. K. P. Ananth and the project engineer is Mr. Mark Golembiewski. This report was authored by Mr. Mark Golembiewski.

Stack tests were conducted by members of MRI's Field Programs Section under the supervision of Mr. Bruce DaRos. Lead analysis of the particulate test filter samples was provided by Mr. Murray Williams of the Analytical Chemistry Department at MRI.

MRI is grateful for the assistance and cooperation received from Mr. Charles Pollinger and Mr. Gary Stewart of GSA--Virginia Heating and Refrigeration Plant. We are also indebted to Mr. Jay Campbell of the National Center for Resource Recovery and his associates Mr. Jerry O'Brien and Mr. Bob Fretz for their vital efforts in arranging and coordinating the d-RDF test burn program, and for their work in the fuel sample collection and analysis.

SECTION 1

SUMMARY

A brief test program was carried out at the Virginia Heating and Refrigeration Plant to ascertain the potential environmental consequences of using a densified refuse-derived fuel as a supplemental fuel for coal. Emission tests were conducted first at baseline conditions (coal only firing), and then when firing blends of 20% d-RDF:80% coal and 60% d-RDF:40% coal. One day of sampling was devoted to each separate fuel mode.

Based on the results presented in this report (Section 4), the following observations regarding the effects of refuse co-firing on boiler emissions can be made.

- Particulate emissions were reduced from 22 to 38% when d-RDF was blended with the original coal fuel. Filterable particulate emissions were lowest when using the 20% d-RDF blend and rose again when the proportion of d-RDF was raised to 60%. This finding may not be conclusive, however, since the boiler load was held steady during the 20% d-RDF firing but not during the 60% mode. Further tests, conducted over longer periods of time, and at consistent boiler conditions, are needed to substantiate the observed trend.

- The amount of particulate lead emitted when burning d-RDF with coal is substantially higher than that from combustion of coal alone and may be a cause for environmental concern. Approximately 200% more lead was emitted during firing of the 20% d-RDF blend (an average of 1,000 $\mu g/m^3$ versus 330 $\mu g/m^3$ during coal combustion), and 580% more (2,260 $\mu g/m^3$) when the 60% d-RDF fuel was used.

- Concentrations of sulfur dioxide, nitrogen oxides and carbon monoxide all decreased slightly when the RDF was used with coal. Because of the very low sulfur content of d-RDF, SO_2 emissions were reduced progressively as the proportion of d-RDF with coal was increased. NO_x and CO levels, however, are highly dependent on boiler combustion conditions which may or may not have been the direct result of burning d-RDF.

- Chloride emissions showed no definite trend which could be used to correlate chloride emissions with RDF modes, though slightly higher concentrations of HCl were observed in two of the samples collected during combustion of the 60% d-RDF blend.

In summary, co-firing of d-RDF with coal at the Virginia Heating and Refrigeration Plant appears to be a viable option from an environmental standpoint. However, the role of lead emissions must be considered when making a final evaluation of the overall potential of d-RDF substitution.

SECTION 2

INTRODUCTION

The Virginia Heating and Refrigeration Plant in Arlington, Virginia, is operated by the General Services Administration (GSA) for the purpose of satisfying the steam heat and chilled water needs of the Pentagon and the Henderson Hall office building. The heating plant consists of five coal-fired boilers, one of which (No. 4) was utilized for the testing described in this report.

The National Center for Resource Recovery (NCRR) in Washington, D.C., is concerned with developing the use of refuse-derived fuel (RDF) as an alternative energy source. With this intent, discussions were held with represenentatives of GSA concerning possible use of densified RDF as a supplemental fuel for their coal-fired boilers. The outcome of these discussions was an agreement to test fire a coal-RDF fuel mixture at the Virginia Heating and Refrigeration Plant (VHRP) and evaluate the subsequent effects on boiler operation and air emissions. The U.S. Environmental Protection Agency (EPA), with Midwest Research Institute (MRI) as contractor, provided air sampling and analysis capabilities.

The test burn and air sampling activities were conducted during the week of March 19-23, 1979 and results of those emission tests are described herein. Subsequent sections of this report present a description of the boiler test facility, an overview of the sampling and analytical methodologies employed, and a discussion of the test results.

SECTION 3

TEST FACILITY

The No. 4 boiler at VHRP was manufactured by the Riley Stoker Company and installed in 1941. It is an underfeed-retort stoker boiler with a rated steam capacity of 70,000 lb/hr. Normal maximum operating load for the boiler, however, is about 50,000 lb/hr. A schematic of the boiler with its auxiliary equipment is shown in Figure 1.

Coal is supplied to the plant from an outdoor storage pile or directly from rail cars via an underground belt conveyor. From this conveyor, the coal is transferred to a bucket conveyor which feeds a coal bunker located above the boiler. During the test burn program, the d-RDF pellets were fed to the same bucket conveyor, using a second belt conveyor. The specified volume ratio of pellets to coal was maintained in each bucket through the use of throttling plates at the conveyor transfer points. The coal/d-RDF mixtures were also transferred to the same overhead bunker that is normally used for coal feeding.

From the bunker, the fuel proceeds by gravity feed to two automatic scales, and then to individual feed chutes above the eight stoker rams. The rams push the fuel onto a traveling grate, which is supplied with underfire air from a forced draft fan. Residual (bottom) ash at the end of the grate is discharged into an ash hopper. Periodically, the ash is removed from the hopper using a pneumatic system and is stored in a silo, where a water spray is used to quench the hot material.

Some of the more important specifications of the No. 4 boiler are listed below:

Manufacturer: Riley Stoker Corporation

Type: Three drum, bent-tube; waterwell tubes all four walls

Steam pressure: 862 kPa (125 psig) @ 350°F

Boiler heating surface area: 771 m^2 (8,300 ft^2)

Waterwall heating surface area: 167 m^2 (1,800 ft^2)

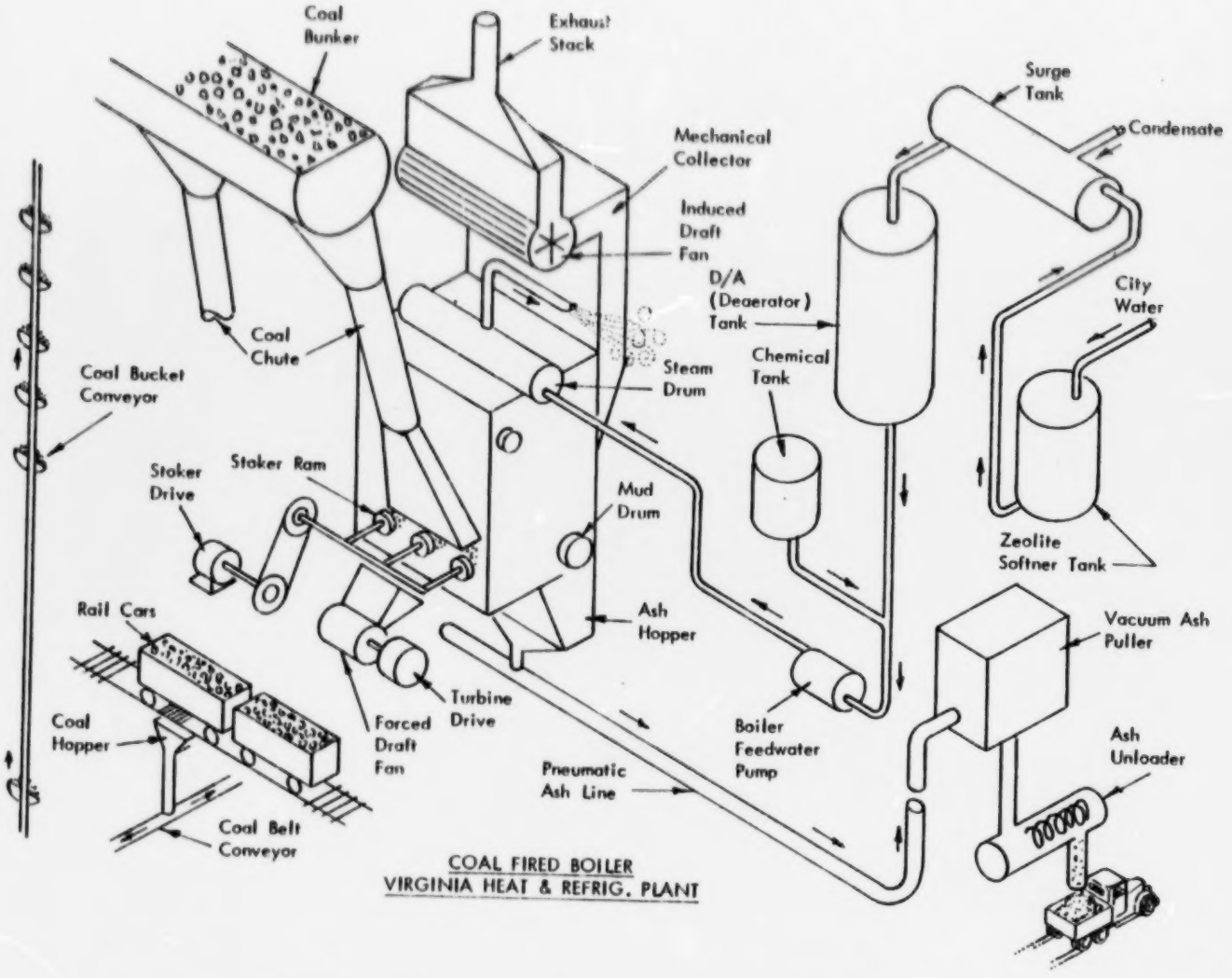

Figure 1. Schematic diagram of the test boiler.

Furnace volume: 105 m^3 (3,700 ft^3)

Projected grate area: 20 m^2 (215 ft^2)

Stoker ram capacity: 5.4 kg (12 lb)/stroke

The design grate loading is 35 lb of coal burned per ft^2 of grate. For coal with a heating value of 13,000 Btu/lb, the heat release rate is 455,000 Btu/ft^2/hr. Overlapping, sliding-plate grates with adjustable stroke are connected to the eight stoker rams via push rods. The moving grates enable the coal to migrate toward the rear of the furnace. Between each retort is a set of air nozzles (tuyeres), through which combustion air is fed. No over-fire air is used in this boiler.

Combustion gases from the boiler are cleaned by a mechanical collector which was installed as original equipment with the boiler. It is a Western Precipitation, type 9-VE, multiclone unit containing 96 cyclone tubes. After exiting the collector, exhaust gases pass through an I.D. fan and are vented via a short, roof-mounted metal stack. Fly ash collected by the multiclone unit is transported, by the same pneumatic line which handles the bottom ash, to the ash silo.

At the time of the MRI tests, a new electrostatic precipitator was being installed to handle exhaust gases from the No. 4 boiler. These units were subsequently made operational during the summer of 1979.

SECTION 4

SAMPLING AND ANALYTICAL METHODOLOGY

The emissions sampling program for the GSA/NCRR d-RDF test burn was designed to characterize boiler exhaust gas emissions when firing coal and when firing two blends of coal and d-RDF. The sampling matrix is illustrated in Figure 2. In addition to the stack testing conducted by MRI, samples of the input fuels as well as bottom ash were collected by NCRR during the test program. The analytical matrices for these samples are also shown in Figure 2.

A summary of the test chronology is presented in the table below.

TABLE 1. PENTAGON BOILER TEST SCHEDULE

Run No.	Date	Fuel Fired	Test Period
1, 2, 3	3/20	100% coal	10:15-18:57
4, 5, 6	3/21	20% d-RDF/80% coal	08:10-17:05
7, 8, 9	3/22	60% d-RDF/40% coal	08:10-17:02
10, 11	3/23	100% coal	08:07-12:49

Brief discussions of the sampling and analytical procedures are presented next. Full descriptions of the methods used are contained in Appendix A.

COAL AND d-RDF FUELS

Hourly grab samples of the fuels (of about one cubic ft) were taken from the weigh station area above the ram feed chutes. Each sample was then progressively subdivided to about a 5 kg size using a riffler apparatus and stored in a plastic bag.

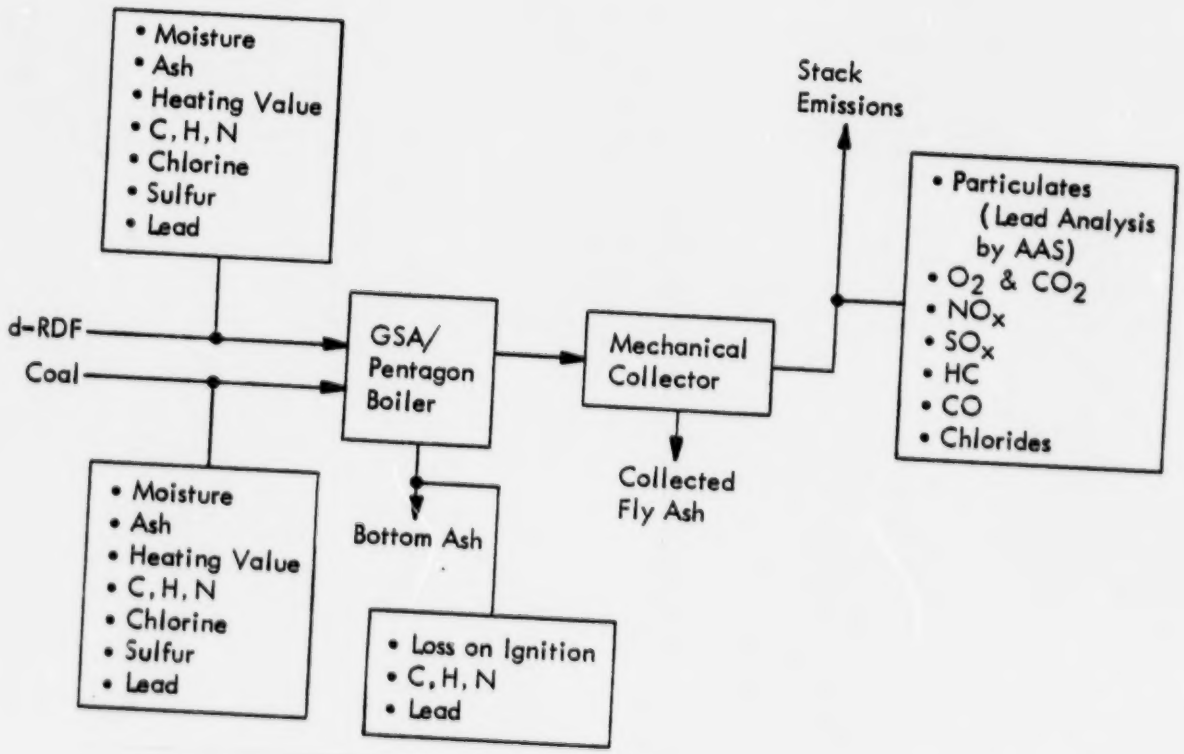

Figure 2. Sampling and analysis matrix.

At the NCRR lab, selected samples were combined to form composite blends corresponding to each MRI particulate sampling run. For the baseline coal tests, composites were prepared using all samples from the test day, rather than for each test period. Composite samples of the coal + d-RDF blends were hand sorted to obtain data on the actual proportion, by weight, or the coal and d-RDF. Analysis at NCRR consisted of determinations of moisture content of the coal and d-RDF portions, of ash content, pellet length distribution and percentage of fines in the d-RDF portions.

Remaining fuel analyses were done by Gilbert Associates. Samples of the coal + d-RDF blends were analyzed for moisture and ash contents as well as for heating values. In addition, one sample of each blend was analyzed for carbon, hydrogen, and nitrogen. To obtain individual data on coal and d-RDF properties, the handsorted coal and d-RDF sample portions were combined to form one sample of coal and one sample of d-RDF. These samples were then analyzed for moisture and ash content, heating value, carbon/hydrogen/nitrogen, sulfur, chlorides, and lead.

Fuel feedrates were determined by using the volume of material fed by the stoker rams. Previous calibration runs indicated a volumetric feedrate of 0.22 ft^3 per ram cycle. Thus, the fuel feedrate was calculated by combining that volumetric value with the number of ram cycles, the number of rams, and the actual feed bulk density (determined by NCRR). The number of ram cycles was recorded every half hour (from counters attached to the ram push rods) and the fuel density every hour.

BOTTOM ASH

Grab samples of the boiler bottom ash were collected twice daily and composited. Analysis was done by Gilbert Associates and consisted of loss-on-ignition, carbon/hydrogen/nitrogen and lead determinations.

STACK EMISSIONS

Samples of the boiler exhaust gases were collected over a 4-day period and later analyzed in the MRI laboratories. The sampling analysis methods used for each of the gas parameters measured are discussed next.

Particulate Concentration

Three EPA Method 5 runs were conducted during each of the three fuel firing modes. In addition, two extra runs were taken during a second baseline coal mode, for a total of five runs when the boiler was supplied with 100% coal. The probe wash, filter catch and impinger contents of each sample were analyzed for net particulate weight. Filter samples were also analyzed for lead content using atomic absorption spectrometry (AAS).

Oxygen and Carbon Dioxide

O_2 and CO_2 contents of the stack gas were measured using Fyrite detectors. Replicate readings were taken during each Method 5 run to determine the molecular weight of the air stream and the percentage of excess air used by the boiler.

Criteria Gaseous Pollutants

Continuous gas analyzers were used to measure the concentrations of O_2, CO, NO_x, SO_2 and total hydrocarbons in the stack effluent on a real-time basis. The sample was drawn through a heated Teflon sample line to a field trailer which housed the monitoring equipment. There, the sample stream was dried and filtered before it was proportioned to each of the analyzers. Instrument responses were registered on strip chart recorders and transcribed to data log sheets at 15 min intervals.

Chlorides

A midget impinger train containing a dilute sodium hydroxide solution was used to collect stack gas samples for chloride analysis. One chloride sample was taken for each Method 5 particulate run (i.e., three per fuel firing mode). Each sample was collected over a half-hour period.

SECTION 5

PRESENTATION AND DISCUSSION OF RESULTS

Results of the MRI/NCRR sampling and analysis program, along with a summary of the boiler operating data taken during the tests, are presented in this section. GSA plant personnel were responsible for controlling operation of the boiler, while NCRR personnel collected samples of the d-RDF/coal blends and recorded the boiler operating parameters. All air emissions sampling and consequent analyses were conducted by MRI.

BOILER OPERATION

With the exception of the second day of the test program (when the 20% d-RDF/80% coal blend was fired), boiler operation data showed uneven conditions during much of the testing period (steam production charts are contained in Appendix C). Steam flow could not be maintained at the desired level of 30,000 lb/hr, primarily because of fluctuating steam demand and the influence of the adjoining on-line boilers when loads changed. A contributing factor to the problem was the need for frequent manual adjustments in ram speed and air flow by the boiler operator. Also, some time after the test program had concluded, GSA stated that the F.D. fan (underfire air) had not worked properly during MRI testing. Instrumentation to monitor boiler conditions, and in some cases the boiler controls themselves, were not available or not functioning for the test program.

Although the full load rating of the No. 4 boiler is 70,000 lb of steam per hour, unseasonably mild weather conditions (and thus reduced steam demand) precluded running the unit near full load conditions. As a result, GSA plant personnel established an operating level of 30,000 lb/hr as one that could be reasonably maintained for the test program.

Table 2 summarizes fuel usage and heat input data from the test program. These data, which have been selected to correspond with the particulate sampling runs, show a wide variation in boiler operation, even among the three runs at each fuel firing condition. Heat input rates during the 11 sampling runs ranged from 23.5 to 82.1 x 10^6 kJ/hr (22.3 to 77.8 x 10^6 Btu/hr).

TABLE 2. SUMMARY OF FUEL USAGE DATA (METRIC UNITS)

Run No.	Feed rates (kg/hr) Coal	Feed rates (kg/hr) d-RDF	Heating value (kJ/kg) Coal	Heating value (kJ/kg) d-RDF	Heat input rate (GJ/hr) Coal	Heat input rate (GJ/hr) d-RDF	Total	% Heat input Coal	% Heat input d-RDF
1	2,253	-	32,378	-	72.9	-	72.9	100	-
2	1,074	-			34.8	-	34.8	100	-
3	726	-			23.5	-	23.5	100	-
4	2,004	340	32,278	18,031	64.9	6.1	71.0	91.4	8.6
5	1,002	118			32.4	2.1	34.5	93.9	6.5
6	1,376	272			44.5	5.0	49.5	90.0	10.0
7	985	1,026	32,378	18,222	31.9	18.7	50.6	63.0	37.0
8	1,203	1,325			38.9	24.2	63.1	61.7	38.3
9	1,562	676			50.5	12.3	62.8	80.4	19.6
10	2,586	-	31,757	-	82.1	-	82.1	100	-
11	1,089	-			34.6	-	34.6	100	-

(continued)

TABLE 2. (concluded) (English Units)

Run No.	Feed rates (lb/hr) Coal	d-RDF	Heating value (Btu/lb) Coal	d-RDF	Heat input rate (MMBtu/hr) Coal	d-RDF	% Heat input Coal	d-RDF
1	4,967	-	13,920	-	69.1	-	100	-
2	2,367	-			32.9	-	100	-
3	1,600	-			22.3	-	100	-
4	4,418	749	13,920	7,752	61.5	5.8	91.4	8.6
5	2,208	259			30.7	2.0	93.9	6.5
6	3,033	600			42.2	4.7	90.0	10.0
7	2,172	2,261	13,920	7,834	30.2	17.7	63.0	37.0
8	2,654	2,921			36.9	22.9	61.7	38.3
9	3,443	1,490			47.9	11.7	80.4	19.6
10	5,700	-	13,653	-	77.8	-	100	-
11	2,400	-			32.8	-	100	-

COAL AND d-RDF FUELS

Two characteristics of the fuel blends are shown in Table 3, the desired versus actual coal/d-RDF proportions and the fuel bulk density. The fuel blend ratios were held close to their desired values with the exception of run nine, when the percentage of d-RDF by weight was only 30.2 instead of 50%. This appeared to be due to the result of segregation of the d-RDF pellets and coal in the feed bunker during charging.

TABLE 3. FUEL BLEND CHARACTERISTICS

Run No.	Fuel mode	Fuel blend (% d-RDF by wt) Desired	Actual	Bulk density (kg/m^3)
1	100% coal	0	0	810
2		0	0	831
3		0	0	877
4	20% d-RDF 80% coal	15	14.5	730
5		15	10.5	766
6		15	16.5	757
7	60% d-RDF 40% coal	50	51.0	641
8		50	52.4	664
9		50	30.2	702
10	100% coal	0	0	790
11		0	0	778

Table 4 presents chemical composition data for the two composite coal samples. Both moisture and ash values were higher for the coal fired at the end of the test program (Runs 10 and 11), which resulted in a slightly lower heating value. All other constituents measured were essentially the same for the two composite samples. In both cases, the lead content was somewhat high, at about 60 ppm.

A similar analysis of the d-RDF fuel is shown in Table 5. Two daily composites were analyzed. Only moisture and lead values differed significantly between the samples. The moisture content was higher in the sample from the first day of d-RDF usage (20% blend), which also contained a much greater concentration of lead than the other composite sample (60% blend). The lead concentration of 124 ppm was about twice that found in the coal samples. However, the other d-RDF composite sample contained a lead concentration of only 16 ppm.

Results of analysis of the coal and d-RDF blend samples are given in Table 6. Moisture, ash and heating value data are averages of the results for samples collected during the three runs at each fuel blend mode. Carbon, hydrogen, and nitrogen results shown in the table were determined from single, selected samples. As one would expect, the blend with the higher proportion of d-RDF had a greater moisture content, a lower ash content and consequently a lower heating value.

BOTTOM ASH

Table 7 presents results of the boiler bottom ash analysis. The percentage of combustible material still remaining in the bottom ash is reflected in the loss-on-ignition values. Both the coal only and the 20% d-RDF blend samples showed a very high proportion of combustible material (over 30%), which would seem to indicate incomplete combustion of the fuels during those two firing modes. Improper boiler operation may likely be the cause of this condition.

Percent carbon in the bottom ash progressively declined, corresponding to the decreasing proportion of coal fired to the boiler. As seen in Table 7, the amount of unburned carbon in the ash from each type of fuel closely parallels the loss-on-ignition values, with the exception of the LOI result for the 20% d-RDF blend. This number is believed to be an anomaly since any combustible material remaining in the bottom ash should be composed almost entirely of unburned carbon due to the long combustion time of the fuel as it is slowly moved along by the traveling grate.

TABLE 4. CHEMICAL COMPOSITION OF COAL FUEL

Constituent	Runs 1, 2 & 3 (3/20/79)	Runs 10 & 11 (3/23/79)
% Moisture	1.9	5.1
% Ash	8.3	10.5
% C	78.6	77.6
% H	5.0	4.8
% N	1.3	1.2
% S	0.9	0.9
% Cl	0.11	0.10
Pb (ppm)	66	59
Higher heating valve (Btu/lb - dry)	13,920	13,650

TABLE 5. CHEMICAL COMPOSITION OF d-RDF FUEL

(DAILY COMPOSITE SAMPLES)

Constituent	3/21/79	3/22/79
% Moisture	27.8	19.4
% Ash	10.6	10.5
% C	46.0	46.7
% H	6.4	6.2
% N	0.16	0.17
% S	0.13	0.17
% Cl	0.16	0.19
Pb (ppm)	124	16
Higher heating value (Btu/lb - dry)	7,750	7,830

TABLE 6. CHARACTERISTICS OF COAL + d-RDF BLENDS

Parameter	20% d-RDF/80% Coal	60% d-RDF/40% Coal
% Moisture	7.3[a/]	10.6[b/]
% Ash	9.5[a/]	8.9[b/]
% C	75.7[c/]	67.2[d/]
% H	5.0[c/]	5.3[d/]
% N	1.14[c/]	0.78[d/]
Higher heating valve (Btu/lb - dry)	13,170[a/]	11,770[b/]

a/ Based on average of samples from Runs 4, 5, & 6.
b/ Based on average of samples from Runs 7, 8, & 9.
c/ Based on sample from Run 6 only.
d/ Based on sample from Run 7 only.

TABLE 7. CHEMICAL COMPOSITION OF BOTTOM ASH

Parameter	Coal Only (Runs 1, 2 & 3)	20% d-RDF/80% Coal (Runs 4, 5 & 6)	60% d-RDF/40% Coal (Runs 7, 8 & 9)
% Loss on ignition	32.9	36.8	11.2
% C	32.3	24.9	11.4
% H	0.10	0.09	0.09
% N	0.10	0.05	0.05
Pb (ppm)	<0.6	<0.6	<0.6

In contrast, the low percentages of hydrogen and nitrogen in the three ashes showed virtually no variation. Therefore, it is apparent that the bottom ash consisted of unburned carbon and inorganic materials.

No significant amounts of lead could be detected in any of the samples. Analysis indicated that lead levels in each case were below the detectability of the instrumental method (0.6 ppm).

STACK EMISSIONS

Results of the sampling and analysis for particulate and gaseous components of the boiler exhaust gases are discussed in this section. It should be realized when reviewing these results that the varying boiler load during much of the test program may have contributed to greater than normal fluctuations in emissions, particularly gaseous effluents, because of changing air/fuel ratios and furnace temperatures.

Particulate Emissions

A complete summary of the EPA Method 5 particulate test results is presented in Table 8, in both English and metric units. A condensed summary of those results is shown in Table 9.

Particulate emissions were highest during this test program when coal alone was used as the boiler fuel. Total particulate concentrations showed no difference between emissions when firing the 20% RDF:80% coal blend and when using the 60% RDF:40% coal mixture. However, filterable particulate results did reflect a change in emissions, but this difference is not seen in the total particulate values because of a wide variation in condensible emissions between the two d-RDF/coal blends. Condensible emissions were highest with the 20% RDF:80% coal blend, by a factor of approximately two over the other two fuel modes. The cause of this high condensible emission is not clear since the same coal and same d-RDF were used throughout the test program. It is likely that load fluctuations during the 60% RDF runs might have caused the wide discrepancy in percent condensibles between the 20% RDF and 60% RDF runs. Table 10 below summarizes the composition analysis of the boiler's flue gas stream.

TABLE 8. SUMMARY OF PARTICULATE SAMPLING RESULTS
(metric units)

NAME	DESCRIPTION	UNITS	1	2	3	4	5	6
	DATE OF RUN		3-20-79	3-20-79	3-20-79	03-21-79	03-21-79	03-21-79
	VOLUME DRY GAS-STD COND	NCM	1.50	1.49	1.52	1.44	1.37	1.48
	PERCENT MOISTURE BY VOL		2.6	3.9	3.2	5.0	5.1	4.6
	AVG STACK TEMPERATURE	DEG.C	327	336	283	301	302	311
	STK FLOWRATE,DRY,STD CN	NM3/MIN	519	535	569	523	482	520
	ACTUAL STACK FLOWRATE	M3/MIN	1082	1152	1111	1075	989	1079
	PERCENT ISOKINETIC		106.9	103.2	99.2	102.0	105.2	105.4
	PERCENT EXCESS AIR		139	282	403	240	189	138
PARTICULATES -- PARTIAL CATCH								
	PARTICULATE WT-PARTIAL	MG	416.1	448.3	357.8	210.0	257.9	301.6
	PART. LOAD-PTL,STD CN	MG/NM3	277.24	309.30	234.52	145.56	188.10	203.44
	PART. LOAD-PTL,STD CN	MG/M3	133.07	139.44	120.10	70.75	91.72	98.08
	PARTIC EMIS-PARTIAL	KG/HR	8.634	9.634	8.005	4.564	5.441	6.349
PARTICULATES -- TOTAL CATCH								
	PARTICULATE WT-TOTAL	MG	451.8	584.5	446.7	371.5	389.5	389.4
	PART. LOAD-TTL,STD CN	MG/NM3	301.03	391.52	292.74	257.53	284.04	262.64
	PART. LOAD-TTL,STD CN	MG/M3	144.48	181.80	149.92	125.18	138.51	126.62
	PARTIC EMIS-TOTAL	KG/HR	9.375	12.560	9.992	8.075	8.216	8.196
	PERC IMPINGER CATCH		7.90	23.30	19.89	43.48	33.78	22.54

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(continued)

TABLE 8. (continued)

NAME	DESCRIPTION	UNITS	7	8	9	10	11
	DATE OF RUN		03-22-79	03-22-79	03-22-79	03-23-79	03-23-79
	VOLUME DRY GAS-STD COND	NCM	1.42	1.52	1.51	1.35	1.47
	PERCENT MOISTURE BY VOL		5.6	5.0	5.6	4.4	4.3
	AVG STACK TEMPERATURE	DEG.C	299	310	301	281	305
	STK FLOWRATE,DRY,STD CN	NM3/MIN	495	537	538	482	525
	ACTUAL STACK FLOWRATE	M3/MIN	1012	1114	1104	948	1076
	PERCENT ISOKINETIC		106.0	105.1	103.9	103.9	104.1
	PERCENT EXCESS AIR		303	293	663	184	132
PARTICULATES -- PARTIAL CATCH							
	PARTICULATE WT-PARTIAL	MG	291.1	363.4	358.7	351.8	538.3
	PART. LOAD-PTL,STD CN	MG/NM3	205.02	237.83	237.22	259.73	364.40
	PART. LOAD-PTL,STD CN	MG/M3	100.26	114.75	115.66	132.06	177.69
	PARTIC EMIS-PARTIAL	KG/HR	6.090	7.666	7.657	7.514	11.472
PARTICULATES -- TOTAL CATCH							
	PARTICULATE WT-TOTAL	MG	333.1	450.5	418.5	419.2	612.1
	PART. LOAD-TTL,STD CN	MG/NM3	234.60	294.88	276.78	309.47	414.37
	PART. LOAD-TTL,STD CN	MG/M3	114.73	142.27	134.94	157.36	202.05
	PARTIC EMIS-TOTAL	KG/HR	6.968	9.505	8.934	8.953	13.045
	PERC IMPINGER CATCH		12.61	19.35	14.29	16.07	12.06

(continued)

TABLE 8. (continued)

NAME	DESCRIPTION	UNITS	1	2	3	4	5	6
	DATE OF RUN		1-20-79	1-20-79	1-20-79	03-21-79	03-21-79	03-21-79
	VOL DRY GAS-STD COND	DSCF	52.89	52.61	53.77	50.83	48.33	52.25
	PERCENT MOISTURE BY VOL		2.6	3.9	3.2	5.0	5.1	4.6
	AVG STACK TEMPERATURE	DEG.F	621	637	542	574	575	591
	STK FLOWRATE, DRY,STD CN	DSCFM	18333	18885	20094	18457	17027	18372
	ACTUAL STACK FLOWRATE	ACFM	38197	40671	39238	37972	34918	38105
	PERCENT ISOKINETIC		106.9	103.2	99.2	102.0	105.2	105.4
	PERCENT EXCESS AIR		139	282	403	240	189	138
PARTICULATES -- PARTIAL CATCH								
	PARTICULATE WT-PARTIAL	MG	416.1	448.3	357.8	210.0	257.9	301.6
	PART.LOAD-PTL,STD CN	GR/DSCF	.12115	.13123	.10249	.06361	.08220	.08890
	PART.LOAD-PTL,STK CN	GR/ACF	.05215	.05094	.05248	.03092	.04008	.04286
	PARTIC EMIS-PARTIAL	LB/HR	19.04	21.24	17.65	10.06	11.99	14.00
PARTICULATES -- TOTAL CATCH								
	PARTICULATE WT-TOTAL	MG	451.8	584.5	446.7	371.5	389.5	389.4
	PART.LOAD-TTL,STD CN	GR/DSCF	.13155	.17109	.12793	.11254	.12413	.11477
	PART.LOAD-TTL,STK CN	GR/ACF	.05614	.07944	.06551	.05470	.06053	.05533
	PARTIC EMIS-TOTAL	LB/HR	20.67	27.69	22.03	17.80	18.11	18.07
	PERC IMPINGER CATCH		7.90	23.30	19.89	43.48	33.78	22.54

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(continued)

TABLE 8. (concluded)

NAME	DESCRIPTION	UNITS	7	8	9	10	11
	DATE OF RUN		03-22-79	03-22-79	03-22-79	03-23-79	03-23-79
	VOL DRY GAS-STD COND	DSCF	50.04	53.84	53.28	47.73	52.06
	PERCENT MOISTURE BY VOL		5.6	5.0	5.6	4.4	4.3
	AVG STACK TEMPERATURE	DEG.F	571	591	574	538	582
	STK FLOWRATE, DRY,STD CN	DSCFM	17486	18975	19002	17031	18532
	ACTUAL STACK FLOWRATE	ACFM	35756	39328	38974	33495	38006
	PERCENT ISOKINETIC		106.0	105.1	103.9	103.9	104.1
	PERCENT EXCESS AIR		303	293	663	184	132
PARTICULATES -- PARTIAL CATCH							
	PARTICULATE WT-PARTIAL	MG	291.1	363.4	358.7	351.8	538.3
	PART.LOAD-PTL,STD CN	GR/DSCF	.08959	.10393	.10367	.11350	.15924
	PART.LOAD-PTL,STK CN	GR/ACF	.04381	.05014	.05054	.05771	.07765
	PARTIC EMIS-PARTIAL	LB/HR	13.43	16.90	16.88	16.57	25.29
PARTICULATES -- TOTAL CATCH							
	PARTICULATE WT-TOTAL	MG	333.1	450.5	418.5	419.2	612.1
	PART.LOAD-TTL,STD CN	GR/DSCF	.10252	.12886	.12095	.13524	.18108
	PART.LOAD-TTL,STK CN	GR/ACF	.05014	.06217	.05897	.06876	.08830
	PARTIC EMIS-TOTAL	LB/HR	15.36	20.95	19.70	19.74	28.76
	PERC IMPINGER CATCH		12.61	19.35	14.29	16.07	12.06

TABLE 9. AVERAGE PARTICULATE CONCENTRATIONS FOR EACH FUEL FIRING MODE (gr/dscf)

Fuel mode	Filterable particulate	Total particulate	Percent condensibles
100% coal[a/]	0.127	0.151	15.6
20% RDF 80% coal	0.078	0.117	33.3
60% RDF 40% coal	0.099	0.117	15.4

a/ Average of five runs.

TABLE 10. AVERAGE GAS COMPOSITION VALUES FOR EACH FUEL MODE

Fuel mode	% O_2	% CO_2	CO (ppm)	% Excess air
100% coal[a/]	14.8	4.9	65	228
20% d-RDF 80% coal	14.3	6.9	22	189
60% d-RDF 40% coal	17.7	2.8	35	420

a/ Average of five runs.

Particulate Lead Analysis

Filter samples from the Method 5 particulate runs were analyzed by AAS for lead content. Results are presented in Table 11. Lead emissions, based on these analyses, showed a definite increase corresponding to the amount of d-RDF fuel blended with coal. When 100% coal was supplied to the boiler, lead emissions averaged 330 $\mu g/m^3$, as compared to 1,000 $\mu g/m^3$ when the 20% RDF blend was introduced and 2,260 $\mu g/m^3$ during firing of the 60% blend. It should be noted that these concentrations were derived only from particulate collected on the Method 5 filter samples and that additional amounts of lead may well be present both as particulate adhering to the sampling probe walls (prior to the filter) and as vaporous lead which could have passed through the filter uncollected.

TABLE 11. SUMMARY OF LEAD EMISSIONS BASED ON PARTICULATE SAMPLING RESULTS[a/]

Run No.	Firing Mode	Lead concentration	
		$\mu g/g$[b/]	$\mu g/m^3$[c/]
1	100% coal	1,300	100
2		1,060	195
3		1,610	250
4	20% RDF + 80% coal	7,700	830
5		11,100	1,100
6		10,400	1,080
7	60% RDF + 40% coal	19,900	2,610
8		7,800	1,320
9		22,900	2,850
10	100% coal	7,430	820
11		1,760	280

a/ Lead concentrations were determined using only filter samples from the Method 5 particulate runs.

b/ Micrograms of lead per gram of particulate collected on the filters.

c/ Micrograms of lead per dry standard cubic meter of air sampled.

Gaseous Pollutants

Gaseous criteria pollutant concentrations measured during the MRI tests are shown in Table 12. The results presented are averages of instrument readings taken at 15-min intervals during the course of each test day. Also shown are the daily ranges of the pollutant concentrations detected. Levels of SO_2, NO_x, and CO all appeared to decrease when the d-RDF fuel blends were introduced. SO_2, in particular, showed a progressive reduction in concentration as the amount of d-RDF blended with coal increased. However, no significant change was observed in emissions of total hydrocarbons (THC) when the fuel blends were changed. THC levels were quite low in all cases (< 10 ppm).

Although data for the 20% RDF test day are reported in Table 12, these values resulted from a shorter sampling period than the other fuel blends because the continuous monitoring system was not functioning properly during much of the 20% RDF test day.

Chloride Emissions

Emissions of hydrogen chloride measured during the test program are summarized in Table 13. HCl concentrations varied quite widely and therefore no definite relationship can be found correlating chlorides with the type of fuel used. Chloride values for the first 100% coal runs were similar to the values for the runs using the 20% d-RDF blend. The highest HCl concentrations (runs 8 and 9) resulted from combustion of the 60% d-RDF blend, although one of the 60% values (run 7) was much lower than the other two. Thus, it is difficult to draw firm conclusions from this set of data about the effect of d-RDF usage on chloride emissions even though one normally experts chloride emissions to increase when RDF is used.

TABLE 12. SUMMARY OF GASEOUS EFFLUENT MEASUREMENTS[a]

Firing mode	SO_2 (ppm)		NO_x (ppm)[b]		THC (ppm)[c]		CO (ppm)		O_2 (%)	
	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
100% coal (3/20/79)	380	240-630	120	64-185	9	4-12	67	5-230	14	7-19
20% RDF[d] 80% coal	330	210-475	60	25-120	5	1-7	22	15-30	15	12-18
60% RDF 40% coal	250	160-370	70	42-80	3	1-4	35	10-78	15	12-17
100% coal (3/23/79)	300	180-390	110	78-146	2	2	63	20-180	13	10-15

a/ Determined by continuous analyzers.
b/ Nitrogen oxides reported as NO.
c/ Total hydrocarbons reported as propane.
d/ Based on very limited data due to equipment malfunctions.

TABLE 13. SUMMARY OF HCl EMISSIONS[a/]

Run no.	Firing mode	HCl (ppm)
1	100% coal	105
2		NR[b/]
3		31
4	20% RDF 80% coal	NR[b/]
5		39
6		105
7	60% RDF 40% coal	48
8		167
9		140
10	100% coal	103
11		105

a/ Determined using impinger sampling train containing NaOH solution.

b/ Not reported - analysis showed sample contamination.

APPENDIX A

ANALYTICAL METHODOLOGY

FUELS AND BOTTOM ASH

All analysis of the coal and d-RDF fuel samples, as well as the bottom ash samples was done by Gilbert Associates, Inc., of Reading, Pennsylvania, for NCRR and basically followed standard ASTM procedures. The individual methods employed are listed below.

Coal

Sample preparation	ASTM D-2013
Moisture	ASTM D-3173
Ash	ASTM D-3174
Higher heating value	ASTM D-2015
Carbon and hydrogen	ASTM D-3178
Nitrogen	ASTM D-3179
Chlorine	ASTM E-38.01 Draft standard - Test method for forms of chlorine in refuse-derived fuel
Sulfur	Leco Automated Sulfur Analyzer
Lead	ASTM D-3683

d-RDF

Sample Preparation	ASTM E 38.01 Draft-Standard Method of Preparation of RDF-3 Samples for Analysis
Moisture	ASTM E 38.01 Draft-Standard Method of Air Dry Moisture Test for RDF-3 and ASTM E 38.01 Draft-Standard Method of Test for Residual Moisture in RDF Analysis Sample
Ash	ASTM E 38.01 Draft-Ash in the Analysis Sample of Refuse-Derived Fuel (RDF-3)
Higher Heating Value	ASTM E 38.01 Draft Test for Gross Calorific Value of Refuse-Derived Fuel (RDF-3) by the Bomb Calorimeter

Carbon and Hydrogen	ASTM D 3178
Nitrogen	ASTM D 3179
Chlorine	ASTM E 38.01 Draft-Test Method for Forms of Chlroine in Refuse-Derived Fuel
Lead	ASTM D 3683 Trace Elements in Coal and Coke Ash by Atomic Absorption
Sulfur	Leco Automated Sulfur Analyzer

d-RDF and Coal Blends

Sample Preparation	ASTM E 38.01 Draft-Standard Method of Preparation of RDF-3 Samples for Analysis
Moisture	ASTM E 38.01 Draft-Standard Method of Air Dry Moisture Test for RDF-3 and ASTM E 38.01 Draft-Standard Method of Test for Residual Moisture in RDF Analysis Sample
Ash	ASTM E 38.01 Draft-Ash in the Analysis Sample of Refuse-Derived Fuel (RDF-3)
Higher Heating Value	ASTM E 38.01 Draft Test for Gross Calorific Value of Refuse-Derived Fuel (RDF-3) by the Bomb Calorimeter
Carbon and Hydrogen	ASTM D 3178
Nitrogen	ASTM D 3179

Bottom Ash

Loss on Ignition	Bureau of Mines Bulletin 638 Methods for Analyzing Coal and Coke Ash Ignition Loss at 800°C and ASTM C 311 Sampling and Testing Fly Ash for Use as an Admixture in Portland Cement Concrete, Loss on Ignition
Carbon and Hydrogen	ASTM D 3178
Nitrogen	ASTM D 3179
Lead	ASTM D 3683

METHOD 5 PARTICULATE SAMPLES

Samples

Particulate weights were determined for the probe rinse, cyclone, filter, ether/chloroform extract residue, and water residue from each sample train. Laboratory and field blanks were also included in the analyses. These blanks include: filters, solvents used for rinsing and sample extraction, and water used to fill the impingers.

Sample Preparation

Gelman Type A/E (fiberglass) filters for the Method 5 train were dessicated prior to taring in a controlled humidity environment. Reweighings under comparable conditions were performed to determine the weight of particulate on the filters after sampling.

Acetone was used to rinse the probes of the Method 5 trains. The rinse from the front half of the filter holder was also included in the probe rinse. These rinses were evaporated as separate samples and included as part of the front half weight.

Liquid samples from the impingers were analyzed for organic material by extraction with three 25-ml portions of chloroform followed by extraction with three 25-ml portions of ethyl ether.[1/] The chloroform and ether extracts were combined in previously dessicated and tared beakers. The extracts were then evaporated to dryness under a stream of prepurified nitrogen. After extraction, the remaining water samples were poured into similarly treated beakers and evaporated to dryness on a steam bath.

Sample Analysis

Particulates, and dried samples, in beakers, were dessicated overnight equilibrated at controlled temperature and humidity for 3 hr, and weighed to the nearest 0.1 mg on an analytical balance. Filters were dessicated to a constant weight.

Quality Assurance

Field blanks of filters, acetone, and water were prepared with the samples. Laboratory blanks consisting of chloroform/ether and control beakers were also prepared and weighed at the same time as the samples. The tare weights and final weights of the filters were made under controlled humidity and temperature conditions. The balance was calibrated using a set of Class S reference weights. Multiple weighings of dried sample materials to constant weight were performed to assure accurate weight determinations.

PARTICULATE LEAD

Eleven filters from the Method 5 particulate runs and five filter blanks were analyzed.

Sample Preparation

A section was removed from each of the filters prior to digestion. Each section was then weighed and the area of the section calculated.

The sectioned samples were reflexed with 5 ml of ultrapure HNO_3, then reflexed with 5 ml of ultrapure HCl/HNO_3 (7:3, V/V). After digestion, the samples were centrifuged, rinsed twice, the supernatants evaporated to <10 ml, and then diluted to a 10 ml final volume with deionized water.

Sample Analysis

Lead analysis was conducted using a Varian AA-6 flame atomic absorption spectrophotometer, equipped with background correction. Samples were aspirated into an air-acetylene flame. Results are presented in Table A-1.

Quality Assurance

Reagent blanks, fortified reagent blanks, fortified samples, and one duplicate sample were analyzed to provide quality assurance data. Also, a method of standard additions was used to verify the concentration of one sample. These results are presented in Table A-2.

CHLORIDES

Samples

Components of the chloride sampling train from eleven sampling runs were analyzed using a method developed by MRI under EPA contract.

Sample Preparation

Probe Plug--

Using a small glass funnel and Whatmann No. 1 filter paper, the probe plug is rinsed with distilled-deionized water, and the rinse is filtered directly into a 50 ml volumetric flask. Using a polyethylene squeeze bottle, $\sim$10 ml of water is squirted directly into the plug in the sample container. The cap is then replaced and secured, and the bottle is shaken several times. The cap is then removed and the rinse water is poured into the funnel containing the filter paper. This process is repeated twice with $\sim$ 10 ml portions of water. After the final rinse, the water soaked up by the plug is recovered by squeezing the plug against the side of the sample bottle

TABLE A-1. LEAD RESULTS

Sample	Original weight[a] (g)	Section weight (g)	Lead on section (μg)	Lead concentration on section (μg/g)	Total lead on filter[a] (g)
1W	0.11187	0.0265	35	1,300	150
2W	0.27566	0.1030	108	1,060	290
3W	-	-	< 1	-	-
4W	0.23614	0.0660	106	1,610	380
5W	0.16010	0.0726	559	7,700	1,200
6W	-	-	< 1	-	-
7W	0.13405	0.0420	466	11,100	1,500
8W	0.15363	0.0564	587	10,400	1,600
9W	-	-	< 1	-	-
10W	0.18368	0.0694	1,380	19,900	3,700
11W	0.24971	0.0731	573	7,800	2,000
12W	-	-	< 1	-	-
13W	0.18642	0.0717	1,640	22,900	4,300
14W	0.14919	0.0490	364	7,430	1,100
15W	-	-	< 1	-	-
16W	0.23031	0.1127	197	1,760	410

a/ Fragments of the samples were missing prior to receipt for analysis; therefore, the final weight may be inaccurate.

TABLE A-2. QUALITY ASSURANCE RESULTS

Sample	Section weight (g)	Lead in section (μg)	Lead concentration on section (μg/g)	Percent difference between duplicates (%)	Fortification level (μg)	Percent recovery (%)
4W; 4W-B[a/]	0.0660; 0.0912	106; 147,124[b/]	1,610; 1,610	0	-	-
2W; 2W*[c/]	0.1030; 0.0767	109; 195	1,060; 2,540	-	100	110
16W; 16W*[c/]	0.1127; 0.0812	197; 364	1,750; 4,480	-	200	110
Reagent blanks	-	< 1; < 1	-	0	-	-
Fortified reagents	-	47.9; 95.3	-	-	50; 100	96; 95

a/ 4W-B is a duplicate sample.
b/ Standard addition value for sample 4W.
c/ 2W* and 16W* are fortified samples.

with a rubber policeman. The inside of the cap is rinsed, and the flask is filled to the mark with distilled-deionized water.

Probe Wash--

The contents of the probe wash sample container are quantitatively filtered through Whatmann No. 1 filter paper into a 50 ml volumetric flask and diluted to the mark with distilled-deionized water. (Note: a blank for Cl should be determined for the filter paper being used by rinsing a dry filter paper with ~40 ml of distilled-deionized water into a 50 ml volumetric flask, diluting to the mark, and titrating a 10 aliquot with standard $Hg(NO_3)_2$).

First Impinger Catch--

Prior to transferring the contents of the first impinger catch to a 50 ml volumetric flask, the sample is neutralized by adding 6N HNO_3 dropwise to the sample in the sample container. The pH of the sample is checked by using a small glass stirring rod to touch a drop of sample to universal indicator paper. After the sample has been neutralized with acid, it is quantitatively transferred to a 50 ml volumetric flask. Filtering of the sample should not be necessary.

Second Impinger Catch--

Follow the same procedure as outlined for the first impinger catch.

Pretreatment of Samples to Remove Interferences--

The removal of heavy metal ions from samples to be analyzed by this method is essential for accurate results. The technique found to be most effective in accomplishing this task is that of employing an ion exchange resin to physically remove the interfering ions prior to sample analysis. A strong acid type cationic exchange resin, Rexyn 101-H (Fisher Scientific Co.) is used to prepare an ion exchange column. An aliquot of the sample is passed through the column and is then titrated according to the standard procedure. The probe wash sample fractions will always require this pretreatment, and in many cases the first impinger catch must also be treated in this manner prior to analysis.

Sample Analysis

The technique developed for the analysis of HCl samples obtained involves pretreatment of the samples to remove any interfering species, followed by titration for chloride ion using standard mercuric nitrate. The major interfering species likely to be encountered in samples collected from combustion sources are: (a) heavy metal ions, principally Fe, Ni, and V; and (b) sulfite ion produced by oxidation of SO_2 in the sodium hydroxide absorbing solution.

The Mercuric Nitrate Method involves titration of Cl^- with standard $Hg(NO_3)_2$ solution using bromophenol blue diphenylcarbazone mixed indicator. Diphenylcarbazone forms an intensely violet colored complex with the first slight excess of Hg^{++} beyond the equivalence point. The bromophenol blue performs two functions, the first being that it allows for a very accurate adjustment of the pH of the solution to be titrated to the range of 3.2 to 3.4 which is necessary for accurate results; and, secondly, its yellow color in the acid range serves as an excellent background color for detection of the violet colored complex formed at the endpoint.

A 10 ml aliquot of the sample to be titrated and diluted to ~100 ml in a 250 ml erlenmeyer flask. The sample is stirred continuously using a magnetic stirring bar. Five to ten drops of bromophenol blue/dipenzlcarbazone mixed indicator are added to the flask. If the sample is initially alkaline, addition of the indicator will cause the solution to turn blue or red in color. In this case 0.05 N HNO_3 is added dropwise until the solution just turns yellow, and then an extra 1.0 ml of 0.05 N HNO_3 is added to bring the pH of the solution to 3.2-3.4. If the sample is initially acidic, addition of the indicator will cause the sample to turn yellow in color. In this case 0.05N NaOH is added dropwise until the sample turns blue in color. Then 0.05N HNO_3 is added dropwise until the solution just turns yellow in color, and then an extra 1.0 ml of 0.05N HNO_3 is added. Using a 10.0 ml buret (0.05 ml graduation), standard 0.01N $Hg(NO_3)_2$ is added until the appearance of a violet color which persists for several minutes with continuous stirring.

The 0.01 N $Hg(NO_3)_2$ solution is standardized by titrating triplicate 10 ml aliquots of standard 0.01 N NaCl solution using the procedure as outlined above.

Results for the individual components of the sampling train are presented in Table A-3.

TABLE A-3. SUMMARY OF CHLORIDES ANALYSIS (as ppm of HCl)

Run No.	Glass wool filter	Probe wash and 1st impinger	2nd and 3rd impingers	Total
1	11	84.8	8.9	105
2	5.0	<2.1	<2.1	<9.2
3	2.9	23	5.0	31
4	2.9	3.3	2.9	9.1
5	<2.1	29	7.4	39
6	<2.1	89	14	105
7	5.4	37	5.4	48
8	<2.1	157	8.1	167
9	8.2	125	6.5	140
10	<2.1	95	5.0	103
11	<2.1	79	24	105

APPENDIX B

SAMPLING LOCATIONS AND PROCEDURES

SAMPLING LOCATIONS

All air samples were drawn from the No. 4 boiler stack at a location above the roof of the powerhouse. No samples were taken prior to the mechanical dust collector.

Particulate

Samples collected using the EPA Method 5 particulate sampling train were drawn from two sampling ports, which were located at a distance of (3.3) stack diameters (13 ft) downstream and 0.5 stack diameters (1.1 ft) upstream from the nearest flow disturbances. The two ports were 90 degrees apart and located in a plane perpendicular to the air flow. Sampling was conducted at 24 traverse points along each duct diameter.

Figures B-1 and B-2 illustrate the locations of the sampling ports and traverse points.

Chlorides

The HCl sampling train was positioned so that the probe tip was located about 1.5 ft inside the stack, using the West sampling port. The probe remained at the same point in the stack for the duration of the test.

Continuous Analyzers

The sampling probe at the end of the continuous analyzer sample line was inserted in the gas stream through a 1/2 in. hole located near the base of the stack.

SAMPLING PROCEDURES

Particulate

EPA Methods 1 through 5 of the Federal Register, 42(160), August 18, 1977 and 36(159), August 17, 1977 were followed in the sampling and analysis of particulate matter. Figure B-3 is an illustration of the sampling train used.

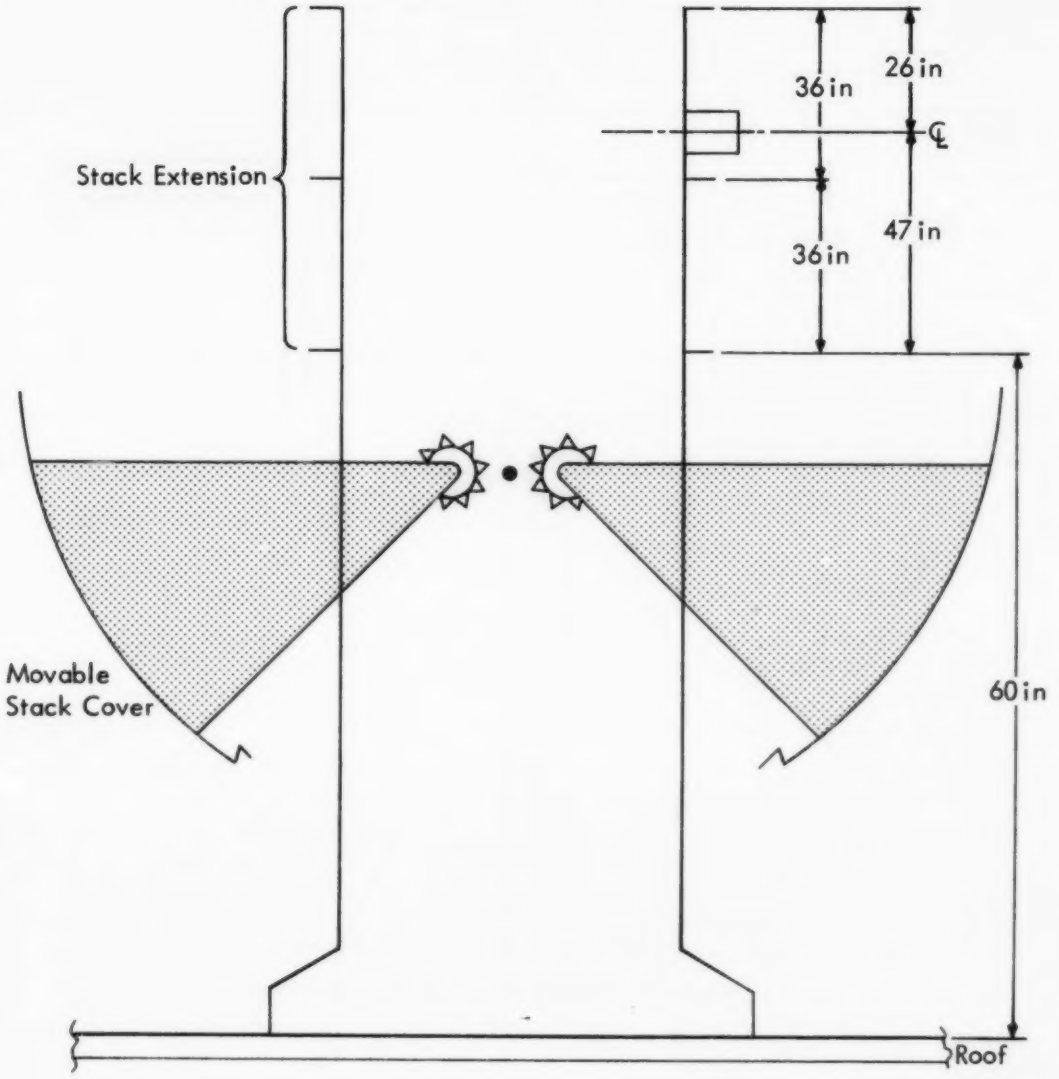


Figure B-1. Diagram of sampling port locations.

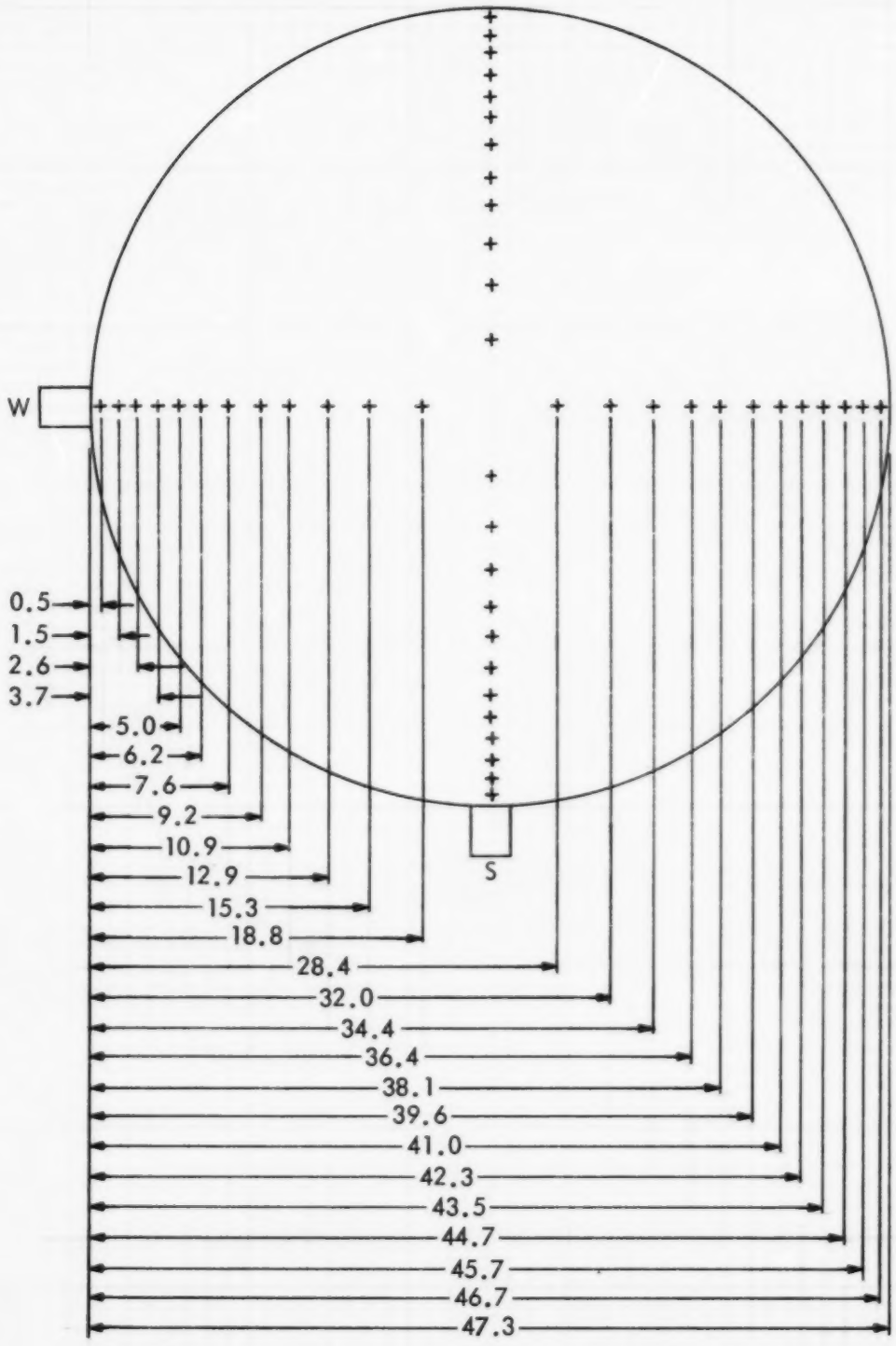
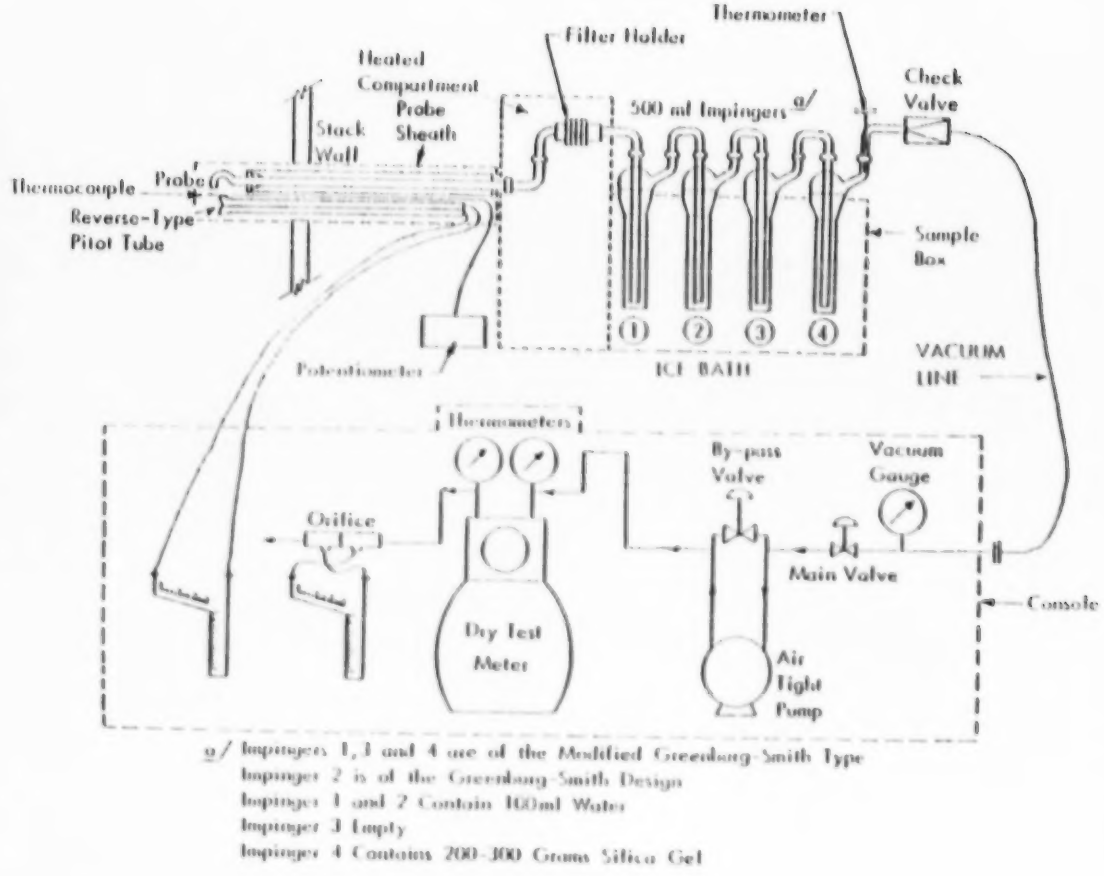


Figure B-2. Schematic illustration of Method 5 sampling points.



a/ Impingers 1, 3 and 4 are of the Modified Greenburg-Smith Type
Impinger 2 is of the Greenburg-Smith Design
Impinger 1 and 2 Contain 100ml Water
Impinger 3 Empty
Impinger 4 Contains 200-300 Grams Silica Gel

Figure B-3. Schematic illustration of EPA Method 5 train used to sample for particulate matter.

A total of 48 traverse points were used to collect each particulate sample. Sampling time at each point was 2 min, for a total of 96 min per sampling run.

Chlorides

The following EPA/MRI sampling method was used to measure HCl concentrations. Each sampling period was 30 min long at a flow rate of approximately 0.04 cfm.

The sampling procedure developed for the determination of hydrogen chloride emissions from stationary sources is basically a modification of the standard procedure for SO_2 determination (EPA Reference Method Six): The HCl method utilizes the same sampling equipment (i.e., probe, glassware, pump, dry gas meter, etc.) with the exception that a regular midget impinger is used for the first impinger in place of the midget bubbler used in Method Six. Dilute NaOH is used as the absorbing solution for HCl. After pretreatment of the impinger catches to remove possible interfering species, samples are analyzed for chloride ion by titration with a standard solution of mercuric nitrate ($Hg(NO_3)_2$).

A heated glass lined probe is used with the temperature maintained at 300 F or at stack temperature, whichever is greater. A pyrex wool plug is inserted in the inlet end of the probe in the same manner as required by Method Six. The impinger train, which should be immersed in an ice bath during the sampling, consists of four midget impingers connected by glass U tubes and clamps. Impinger Nos. 1 and 2 should contain 15 ml of the absorbing solution (0.1N NaOH). Impinger No. 3 should contain 15 ml of 3% H_2O_2 solution, which will remove SO_2 from the sample stream. Impinger No. 4 is a dry impinger which functions to remove moisture from the sample stream. The impinger train is interfaced with the probe by using a short, right angle bend glass adaptor with the appropriate standard taper ground glass joints at either end. A standard Method Six control box with umbilical cord is used to complete the sample train. A sampling rate of 2.0 liters per min is recommended with a total sample volume of 2.0 to 10.0 s.c.f. per sample, depending on the expected concentrations of HCl to be measured. (Note: maximum obtainable sample volume may be dictated by the amount of moisture present in the gas stream being sampled. Excessive build up of water in the first and/or second impinger can lead to carryover of sample into the third impinger.

At the conclusion of a sample run, the probe is removed from the stack, and the probe plug is recovered using a pair of tweezers to place the plug into a marked, 125 ml polyethylene sample container. After the probe has cooled sufficiently, it is rinsed with distilled-deionized water ($\sim$30-35 ml) by using a square bottle to direct the water through the inlet end of the probe while holding it in an elevated position. The rinse is collected at the

outlet end in another marked sample container. The contents of the first impinger are quantitatively transferred to a marked sample container along with a rinse of the probe to first impinger glass adapter. The contents of the second impinger are quantitatively transferred to another sample container along with a rinse of the glass U tube which connects the first and second impingers. The total volume of the impinger catch and rinse in each case should not exceed 40 ml. The contents of the third impinger (SO_2 scrubber) should be discarded, and fresh solution used for each run.

A schematic of the HCl sampling system is shown in Figure B-4.

Continuous Analyzers

The continuous monitoring system for gases consisted of the following gas analyzers:

1. IBC O_2 analyzer; operates on the principle of polarographic cell.

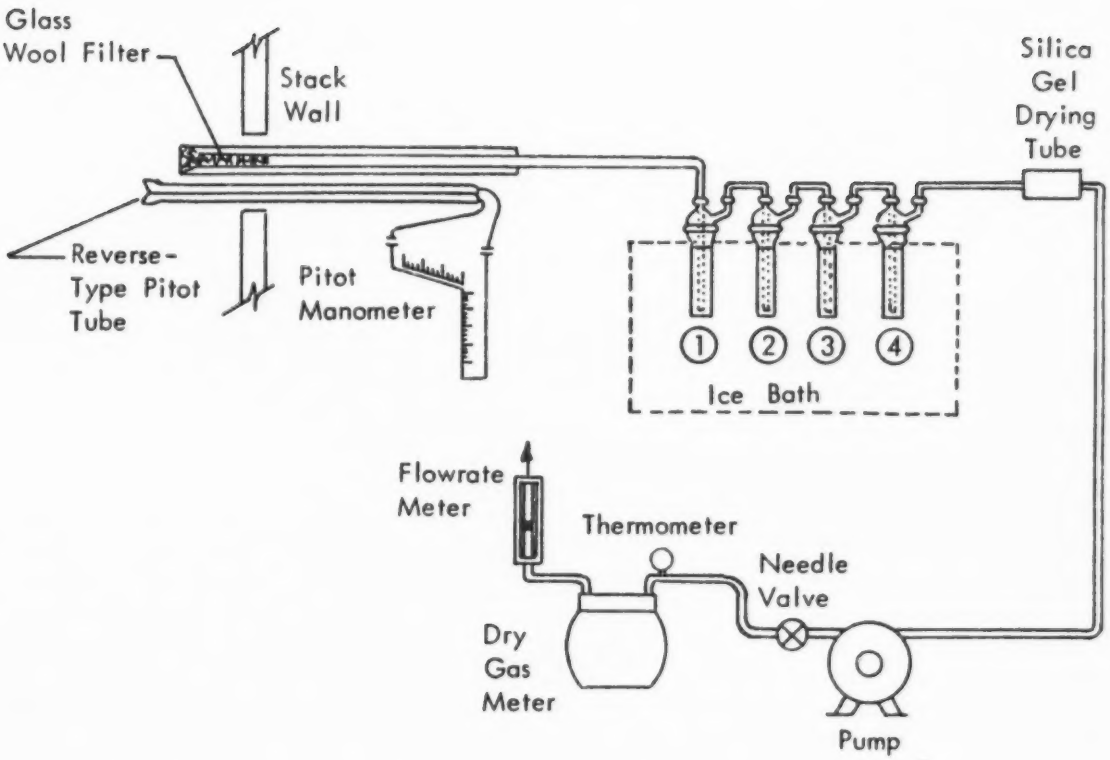
2. Bendix NO_x analyzer; operates on the principle of chemiluminescent.

3. Beckman SO_2 analyzer; operates on the principle of NDIR.

4. Beckman HC analyzer; operates on the principle of FID.

5. Beckman CO analyzer; operates on the principle of NDIR.

A heated, 1/4 in. diameter Teflon sample line was used to transport a continuous stream of the stack gases to a manifold system which was housed in a trailer located at ground level next to the powerhouse building. In the manifold system, the sample stream was dried and filtered prior to being proportioned to each of the analyzers.



① & ② Midget Impinger (15 ml of 0.1 N NaOH)
③ Midget Impinger (15 ml of 3% H_2O_2)
④ Midget Impinger (Dry)

Figure B-4. Schematic diagram of hydrogen chloride sampling train

APPENDIX C

BOILER STEAM OUTPUT CHARTS

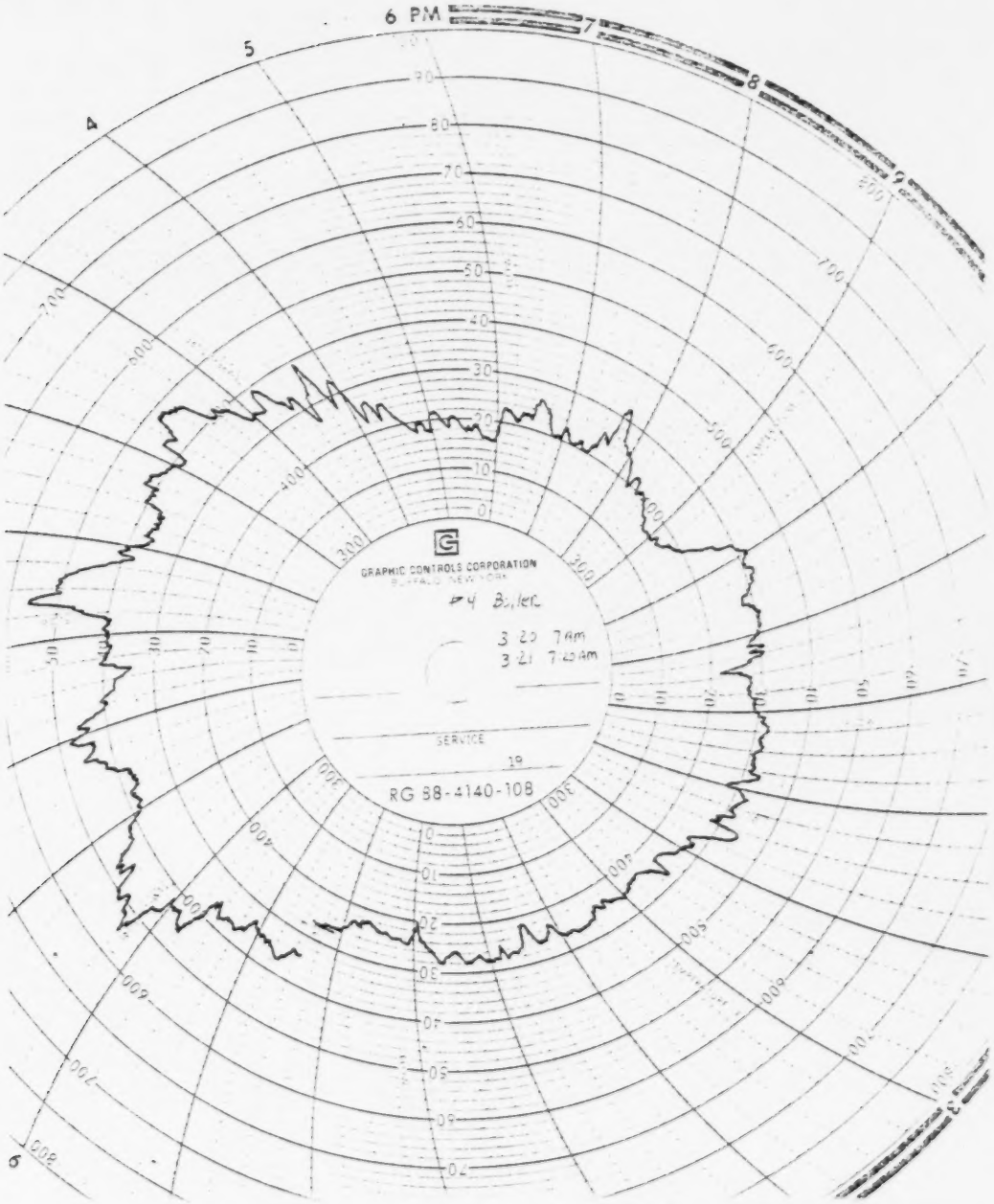


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Figure C-1. Boiler steam chart for 3-20-79 - 100% coal.

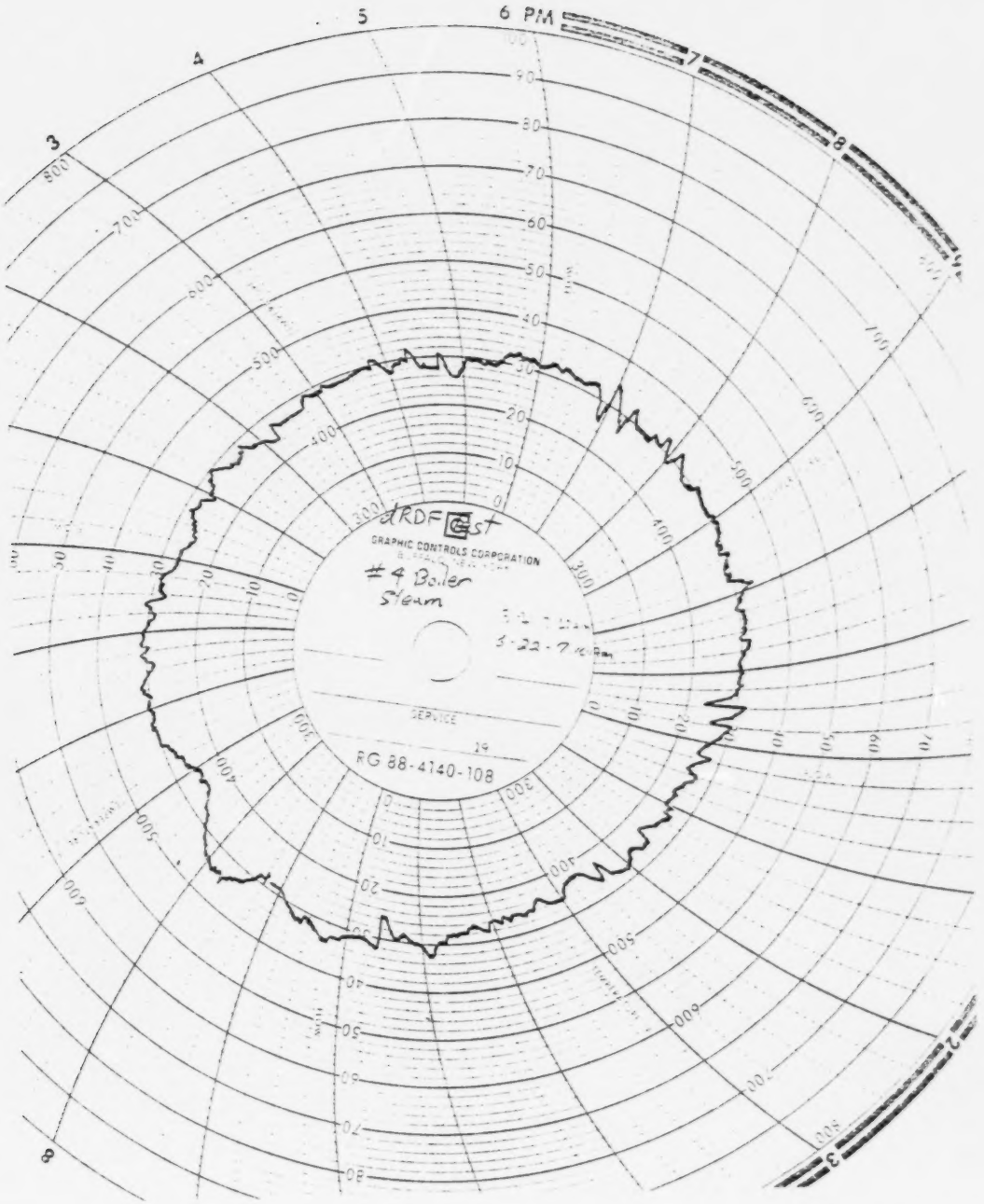

Figure C-2. Boiler steam chart for 3-21-79 - 80% coal + 20% d-RDF.

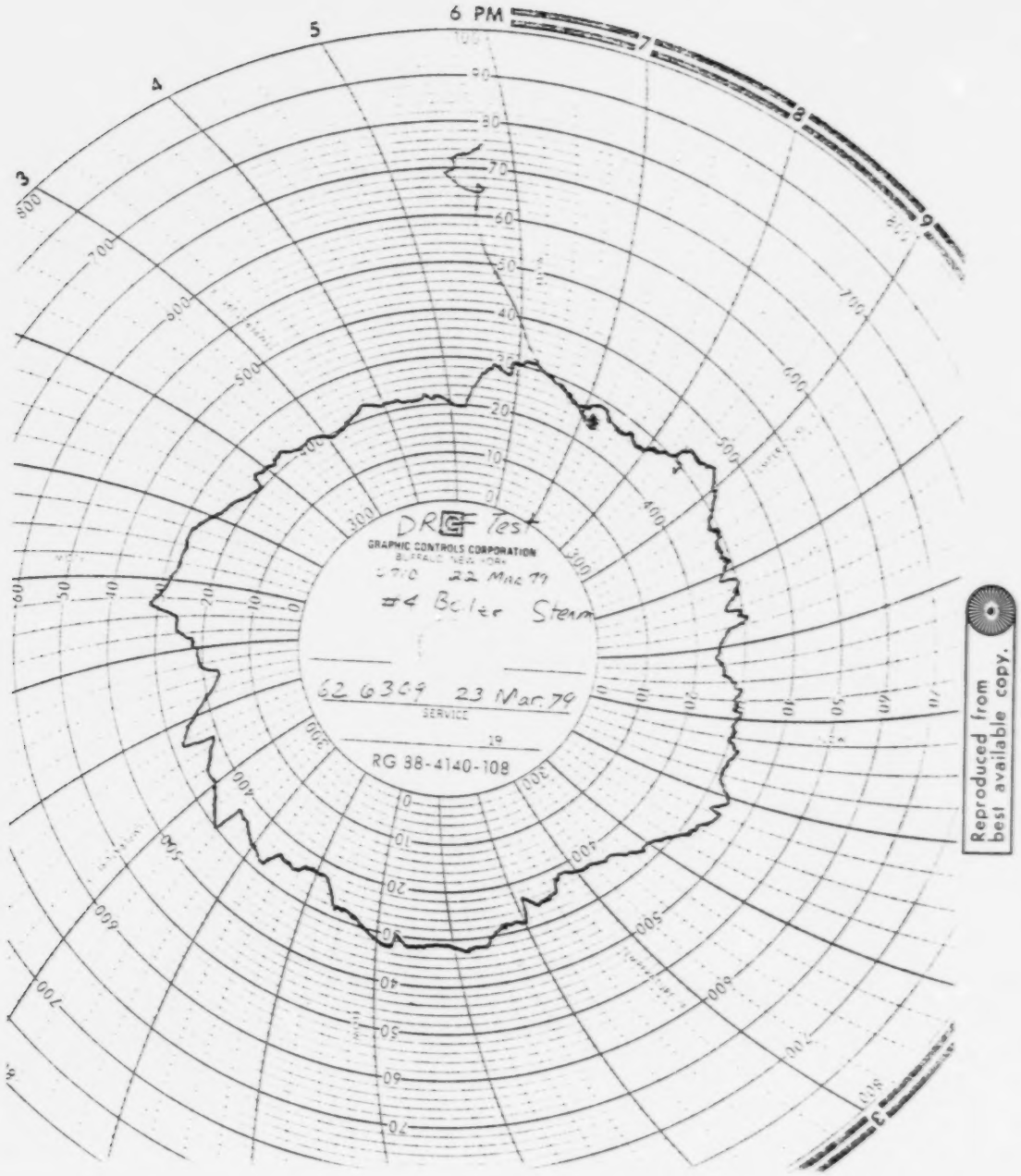

Figure C-3. Boiler steam chart for 3-22-79 - 40% coal + 60% d-RDF.

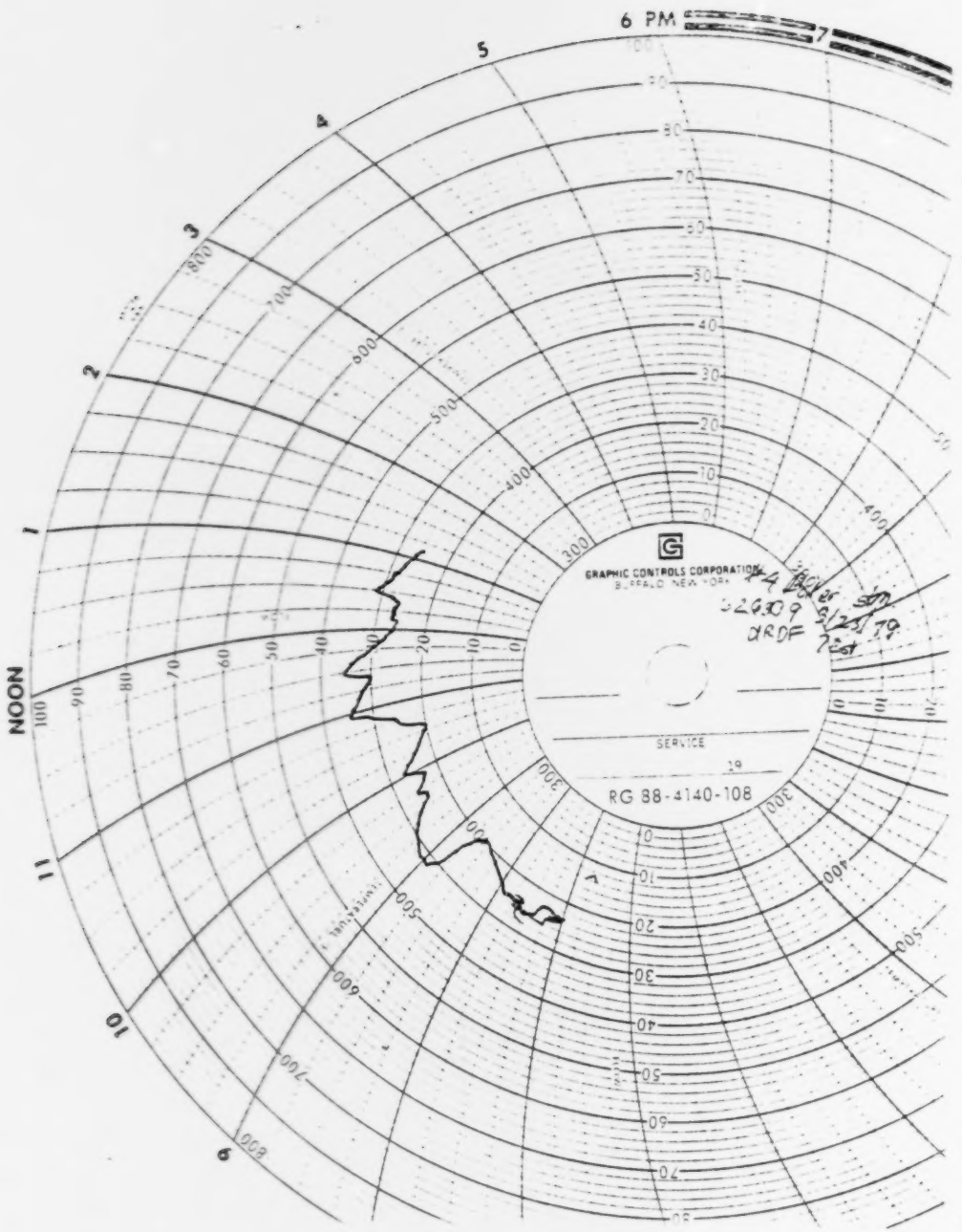

Figure C-4. Boiler steam chart for 3-23-79 - 100% coal.